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Analysis of the net composed of neuronlike elements and compensation of the edge influences

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1. Introduction

The structures composed of neuronlike elements presented in this paper are very interesting for engineers and technicians because of possibilities of their applications in technical arrangements for data processing and pattern recognition. The idea of neuronlike nets and their applications for information processing is based on the results of morphological and neurophysiological investigations of the nervous system (3,4).

The general purpose of this work is recognition and explaining of phenomena taking place in nets composed of neuronlike elements from the point of view of technical applications.

2. Some problems of investigations of structures composed of neuronlike elements

The investigated system is composed of many mutually interconected elements. It is strongly nonlinear, includes integrating and inertial elements. It is of course impossible to analyze the net the model of which would take into consideration all known properties of the nervous system. The appropriate choice of properties of elements is a kind of compromise. On the one hand all properties necessary from the point of view of application should be taken into consideration (in our case the properties connected with the transmission and processing of information), but on the other hand the model should not be too complicated.

The general task of a group of works on the layer nets (2,3, 5,7) was to elaborate the methods of the net analysis and the method of synthesis of systems for informative points detection. The problem was studied by several authors using different methods of structure description.

The basic task of this work is to reconstruct the nets proposed as so far as to minimize the time necessary for detection of informative points.

There are three basic problems and difficulties connected with the analysis of the net:

(i) problem of mathematical description of the net and its elements (the description depends of course on the modelled phenomena and should be as simple as possible),

(ii) choice of method of stability region determining,

(iii) the compensation of edges influences.

The net is composed of neuronlike elements arranged in layers. As a result of previous considerations we have chosen a model of neuronlike elements with the following properties:

(i) the element is a many input summator (it corresponds to spatial summation in neuron) and resultant signal is applied to the inertial element of the first order (it corresponds to the biological effect of temporal summation),

(ii) the output value (frequency of the output impulsation) depends on the input signal by some threshold characteristics,

(iii) there are two kinds of outputs: inhibitory and excitatory. After many authors (1,2,8) we assume that the structure of the net is homogeneous and symmetrical. This assumption is based on the results of investigations of visual tract.

An example of the net organization is a layer with local (in one layer) and global (between layers) connections. There are different systems of functional connections between individual elements and groups of elements. Especially interesting is a scheme when neurons are connected according to the lateral inhibition rule. In this case the well known phenomenon of reduction of information is observed (1,8).

3. One dimensional net - a chain of neurons

Let us consider a simple example of the layer net composed of neuronlike elements - a chain of neurons. Every element of structure affects its neighbours according to the lateral inhibition rule (8). The range of influence is equal to "n" as presented in Fig. 1. The relation between outputs Y and inputs X is described by formula

$$X = A \cdot Y \qquad /1/$$

where X and Y are the column matrices with elements determined by the value of inputs (outputs) and A is a multidiagonal matrix characterizing the connections between the elements (weights). From formula /1/ we are able to determine the distribution of output values and define the stability conditions of the net (8), unfortunately when $n > 1$ this procedure consisting in solving matrix equation $Y = A.X^{-1}$ appears to be very difficult (6).

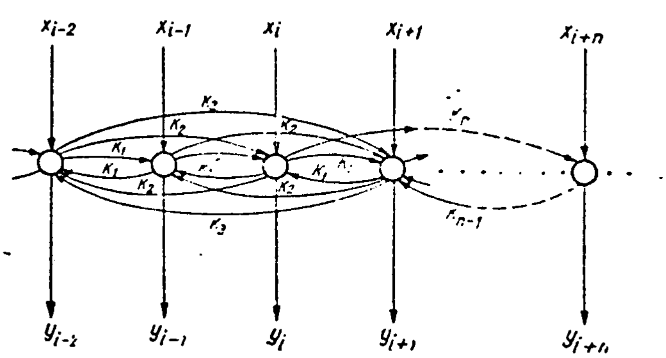

Fig. 1.
One-dimensional net (chain of neurons) with negative feedback. x_i - input signals, y_i - output signals, $k_1, k_2, \ldots, k_n$ - coupling weights of the lateral influence between appropriate elements.

Let us assume that:

(i) the network expands infinitely,
(ii) all elements are identical,
(iii) the operation point is placed in a linear region of a static characteristic.

The general formula describing the relation between the input x_i and output y_i series is described by the difference equation

$$y_i = x_i - \sum_{j=1}^{n} k_j (y_{i-j} + y_{i+j}) \qquad /2/$$

where k_j are the weights of the lateral influences. After the adapted and modified Z-transform method (5,6) we obtain

$$Y(z) = F(z) \, . \, X(z) \qquad /3/$$

where F(z) is a transfer function of the net (equation /6/).

The application of Z-transform method to the difference equation describing the net behaviour allows to define the distribution of the output values (formula /4/) of chain elements

$$y_i = \sum_{n=-\infty}^{+\infty} a_n \, x_{i+n} \, , \qquad /4/$$

where: a_n - coefficients of the Laurent expansion of the function F(z) determined by formula

$$a_n = \frac{1}{2\pi i} \oint F(z) \, . \, z^{-(n+1)} dz \quad . \qquad /5/$$

Of course these values are approximative ones (bacause the real chain has a finite dimension) but the comparison of them with the experimental values (obtained by modelling in digital computer) shows a coincidence to a high degree (Fig. 2.).

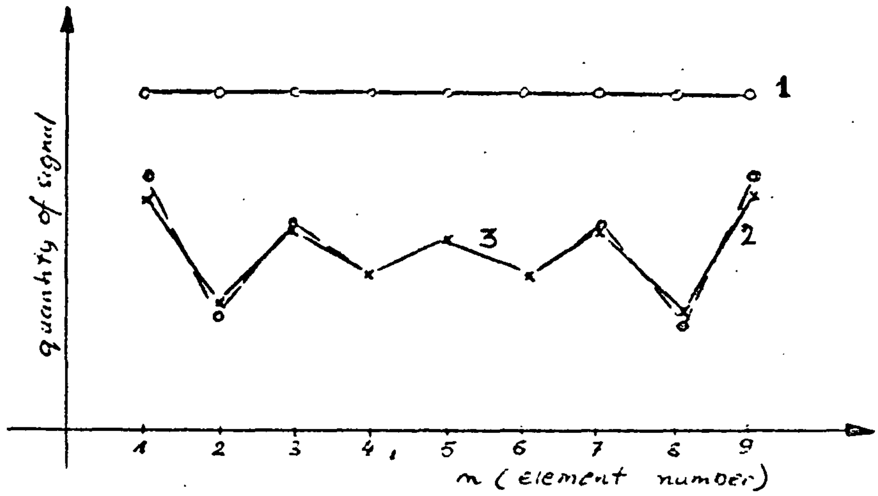

Fig. 2.

The distribution of signals 1 - input signals, 2 - theoretical output signals, 3 - experimental output signals

4. Stability conditions

One important problem which should be solved before the application of the network is the study of their stability. It was found (5) that we can determine the stability conditions putting $z = \exp(j\varrho)$ into the formula /6/ describing a transfer function - for the set from Fig. 1 we obtain

$$F(z) = \left[1 + \sum_{i=1}^{n} k_i \,(z^i + z^{-i}) \right]^{-1} \qquad /6/$$

- and demanding $F(\varrho)$ be always positive for any values of ϱ $(0 \leq \varrho < 2\pi)$.

As an example we shall consider a net when $n = 1$. The inhibitory influence appears only between the output of each element and its two nearest neigbours, the weights are denoted by k_1 . The stability condition is determined by inequality

$$0 < k_1 < 1/2 . \qquad /7/$$

Computation and results for the nets with $n > 1$ can be found in (6).

5. Compensation of the edges influence

It appears, however, that the chain of neurons as a detector of informative points (like edges of excitation or variations in the distribution of excitation) sometime gives a false information (6).

Let us consider an example. The distribution of the excitation is applied to the chain of neurons as shown in Fig. 3a. When the step of the excitation appears near the end of the net then we receive at the outputs fluctutations which make the detection impossible (Fig. 3b). On the other side, when this step is in the middle part of the net then the edges influence is not so destructive and we can recognize the informative point (Fig. 3c).

The edges of the structure give some "reflections", some oscillations and make impossible identification of the informative points. Because that noxious fact is caused by edges, the structure of the net should be reorganized in such a way so as to compensate the influence of the edges and to make the finite net to behave like the infinitely expanding net (the net without the edges).

There are following methods of compensation of the edges influences (6):

(i) a discrete change of weights in the feedback loops of the edges elements,

(ii) an additional self feedback loop for these elements,

(iii) a continuous change of weights.

6. Conclusions

We have examined the behaviour of the net being an element of the identifying and classifying structure, by modelling the chain on digital computer (CDC 3170). We have received the following conclusions:

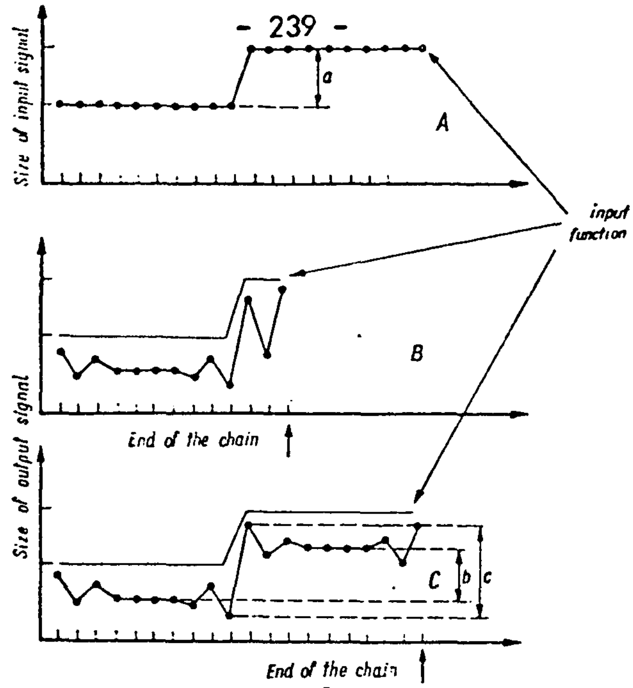

Fig. 3.

Transformation of a step function by a one-dimensional net of Fig. 1. Comparison between a long and a short neuronal chain with negative feedbacks. A - distribution of input signals, B - distribution of output signals when the step is situated near the edge of the net, C - distribution of output signals when the step is situated at the middle of a long net, a - amplitude of step function, b - amplitude difference between steady states, c - increased output amplitude at the step of excitation.

(i) fluctuations at the edges disappeared after the compensation,

(ii) a compensated net reaches the steady state much faster,

(iii) the compensated net is invariant to the position of the picture.

An example of the behaviour of one dimensional structure used as a detector of the informative point like a step of excitation is presented in Fig. 4.

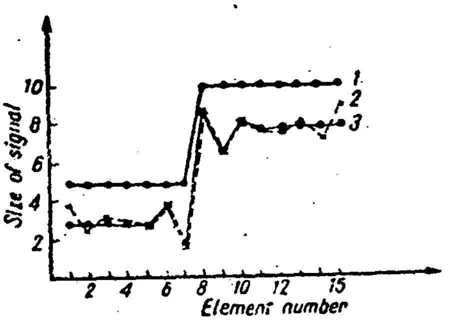

Fig. 4.

Transformation of a step in excitation in two types of nets with negative feedback loops, 1 - input signals, 2 - output signals in the uncompensated net, 3 - output signals in the compensated net.

The same method of analysis can be applied to the two dimensional flat net. By the same method of modified and adapted Z-transform be proved analogous theorems as for a chain (6).

After the many examples modelled at digital computer we obtain the general conclusions: (6).

The algorithms of the compensation assure the independence of detection on the position of pictures and make their classification more exact and sure (6). The net composed from the neuronlike elements may be used as a detector of informative points in technical identification arrangements.

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